U. S. DEPARTMENT OF AGRICULTURE

FARMERS' BULLETIN No. 1606

FARM DRAINAGE

THE DRAINAGE of wet spots in cultivated fields is generally the most profitable type of drainage a farmer can employ, as it results not only in increased crops from the areas drained but also permits the land owner to "square up" the fields so that the land can be cultivated with the minimum of time and labor.

Surface drainage consists in promptly removing water from the ground surface, and is usually accomplished by means of shallow ditches that may be constructed with a plow and scraper or a ditching plow, or by the use of dynamite.

Underdrainage consists of removing excess water from the root zone of the soil, for which purpose tile drains are generally used. Water enters and flows through the tile by gravity, and the drains must have outlet into some watercourse lower than the land to be drained.

Random lines of tile may be laid to drain wet portions of fields, but for land that is uniformly too wet for cultivation a main outlet drain and a system of parallel lateral drains are needed.

In clay soil it may be necessary to place drains from 40 to 70 feet apart and from 2 to 3 feet deep, while in open soils they may be spaced from 80 to 150 feet apart and from 3 to 4 feet deep.

Four-inch tile is the smallest size that should be used. In general, tile receiving no surface water should have sufficient capacity to remove run-off one-fourth inch in depth in 24 hours.

Surface inlets are sometimes provided to admit surface water to tile lines. Where this is done it is necessary to use larger tile and to install silt wells to catch and retain silt carried in by the water.

Vertical drains are not successful except under special conditions, and as a general rule should not be installed where a surface outlet can be obtained at reasonable cost.

For a drain to operate efficiently it must be kept clean. Open ditches and tile outlets should be kept free from weeds, trash, and sediment.

Washington, D. C. Issued October, 1929

FARM DRAINAGE

By LEWIS A. JONES, *Senior Drainage Engineer, Division of Agricultural Engineering, Bureau of Public Roads*

CONTENTS

INTRODUCTION

IN A LARGE PART of the United States, profitable farming is dependent upon artificial drainage of the land. More than 10 per cent of the improved acreage in farms has been provided with ditches or tile drains,[1] but undoubtedly a much greater area is not yielding full return upon the money and labor spent because of inadequate drainage. Great damage to a crop because of inadequate drainage is usually recognized, but too often the loss is considered unavoidable, and it is hoped that the following season will be more favorable. That hope frequently is realized, and a fair crop makes many forget that future seasons will often be unfavorable and that other losses are certain to occur. A poorly drained field, which in some seasons is productive and in others is not, may be more detrimental to a farmer's success than swamp land. When a field is plowed, planted, and cultivated, and then no crop is harvested, not only is the land unproductive, but the labor, fertilizer, and seed likewise are lost.

BENEFITS FROM DRAINAGE

A wet soil is cold, because it takes many times as much heat to warm water as to warm a like quantity of the earthy particles, and relatively almost none to warm the air that replaces the moisture drained from a soil. The bacteria that are necessary in preparing the soil elements for plant food are lacking in a wet soil or are deficient

[1] UNITED STATES DEPARTMENT OF COMMERCE. BUREAU OF THE CENSUS. FOURTEENTH CENSUS OF THE UNITED STATES TAKEN IN THE YEAR 1920. v. 7, p. 372. Washington, [D. C.] 1922.

in numbers, because they require air and warmth. A soil that is wet for long periods is apt to be compact (tight); and when plowed it does not have a good tilth, but is so hard that plant rootlets spread through it slowly and with difficulty, whereas they spread readily through a well-drained soil with good tilth.

Drainage of the soil firms it and fits it for plowing and planting earlier in the spring and permits cultivation sooner after rains than is possible in undrained soil. In a well-drained soil beneficial bacteria can work effectively, plant-food elements are made more rapidly available, and the plants grow faster and stronger.

Drainage of the wet spots makes it possible to plow, plant, or cultivate the entire field at the same time, when the soil is in good condition. A uniform and increased yield usually is obtained over the entire field with the expenditure of less time and labor than was required before the wet spots were drained. In a soil that is saturated nearly to the surface during the spring and early summer, the roots of the crop spread out near the surface. Later, when summer droughts occur, the water table falls below this root zone, and the

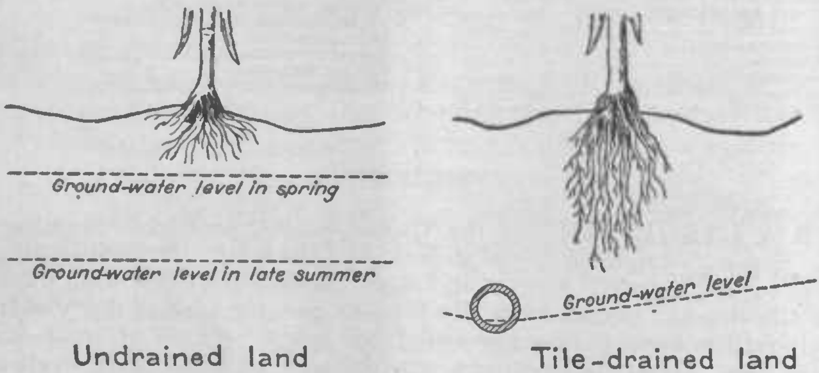

FIGURE 1.—Difference in root systems in drained and undrained soil

crop "burns out." In well-drained land the roots extend downward in the deeper root zone and the plants are better able to withstand the drought. Figure 1 illustrates the difference in root systems in drained and undrained soil. These benefits, which may often be obtained in fields that seem to need little if any drainage, are not sufficiently appreciated.

SURFACE DRAINAGE

Surface drainage is the removal of water from the ground surface, in order that the excess moisture in the soil may be removed as promptly as possible by evaporation from the ground surface and by percolation through the subsoil.

The simplest and cheapest method of surface drainage is by shallow ditches that follow the low depressions through the field. The best locations for the ditches can readily be determined by the farmer after a heavy rain, when the water is standing on the ground. The ditches can be made at any time when the men and teams are not engaged on other work. In this manner the low spots in the field

can gradually be brought into cultivation so that in a few years and with a small outlay of cash the farmer can put his land in much better condition as far as surface drainage is concerned. The benefits received from such work will more than repay the labor and cost involved. However, such drainage is effective only for removing the surface water quickly and making the fields cultivable sooner than would otherwise be possible. To drain the soil itself, it is necessary to dig numerous and comparatively deep open ditches, or to construct underdrains.

FIELD DITCHES

Field ditches are of two kinds, namely, narrow ditches with nearly vertical sides, and V-shaped ditches with flat slopes. The narrow ditches are used in regions where large machinery is not used extensively in farming, and cutting the land into small fields does not interfere to any great extent with farming operations. The V-shaped ditches are more desirable in regions where farming with large machinery is practiced, as they can be crossed with such equipment and their presence does not interfere so greatly with farming operations. The land occupied by both types can not be cultivated and where numerous ditches are required the area lost to cultivation is considerable.

DITCHING WITH MACHINERY

Where the ground is comparatively free from stumps and rocks and sufficiently dry to afford a footing for teams, an ordinary plow and a slip scraper can frequently be used in constructing shallow field ditches such as are required for surface drainage. However, if there is much of such work to do it is generally advisable to use one of the smaller types of ditching plows (fig. 2), which cost from \$65 to \$125. With such plows, V-shaped ditches from 2 to 2½ feet deep can be dug economically, the plow being pulled by horses or by a tractor and drawn back and forth until the ditch has reached the maximum size the plow will construct. In addition to digging ditches, such plows can be used for building terraces and grading roads.

An elevator grader digs ditches rapidly. By using an extension on the carrier that delivers the earth, ditches up to 6 feet in bottom width, 4 feet deep and with side slopes of 2 horizontal to 1 vertical can be built.

Large capstan plow ditchers (fig. 3) are manufactured that dig ditches from 3 to 3½ feet deep with a bottom width of 18 inches and a top width of 4 feet, up to 4 or 5 feet deep with a bottom width of 4 feet and a top width of 12 feet. Such ditchers are pulled by a tractor or by 10 to 12 horses hitched to a cable running from the plow through a series of pulleys to a deadman placed ahead in the line of the ditch. They vary in cost from about \$700 to \$1,500. Such ditchers operate successfully where the ground is free from stumps and rock and is practically level or has a uniform slope, but where the ground is irregular it is difficult to obtain a satisfactory grade. Unless a farmer has a large amount of flat-land ditching to do, the purchase of such a machine is not advisable. Instead, it

FIGURE 2.—Small ditching plow

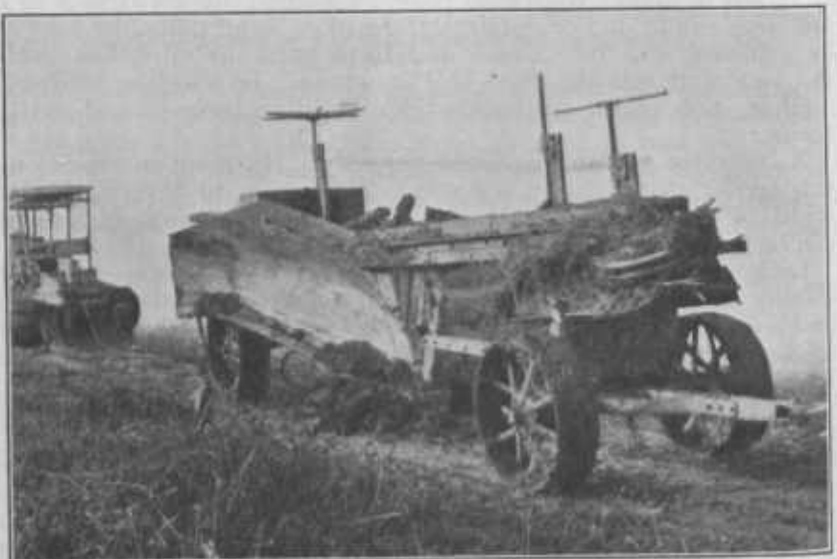

FIGURE 3.—Large capstan plow ditcher

is usually cheaper to engage some drainage contractor who is equipped to do the work.

There are a number of different types of machines designed for constructing large ditches such as usually are required for drainage-district outlets. Detailed descriptions of these machines can be found in another bulletin.[2]

DITCHING WITH DYNAMITE

While ditching with dynamite is possible under almost any conditions, it usually is economical only for making small ditches or cut-offs in stream channels, in soils other than gravel and dry sand. The most economical size of dynamite ditch is about 3 feet in depth and 8 feet in top width; much larger ditches can be built in this manner but the cost per cubic yard of excavation increases rapidly with the size. The ideal material for dynamite ditching is a saturated sedimentary soil that is firm but not as stiff as the hardest clays and is free from stumps and large roots. Many excellent ditches have been blasted under conditions quite different from these, but at increased cost. Where conditions are such that the work is adapted to any one of the several types of ditching machines, it generally is not advisable to use dynamite, but usually it is much cheaper to dig ditches with dynamite than with hand labor.

To blast a ditch with dynamite, a number of small charges are placed in a series of holes along the center line, for a ditch less than 10 feet wide and in two or more rows for wider ditches, and are exploded by one of two methods. In the "propagated" method the charges are so closely spaced that the detonation of one will explode the others. In the "electric" method the charges are connected to an electric blasting machine and all are discharged simultaneously. The first method usually has the advantage of being cheaper, but it can only be used in wet soils. With the electric method the charges are more certain to explode, and therefore this method is sometimes the more economical on account of the saving in time and labor.

There are two kinds of dynamite in general use for ditching, the straight or nitroglycerin, and the extra or ammonia. Both are made in several strengths, designated by percentages, and equal percentages indicate equal strengths as between the two kinds. For explosion by the propagated method, 50 per cent or stronger straight dynamite must be used, while for the electric method the 40 per cent strength of either kind is used. The "extra" dynamite is usually from 1 to 2 cents per pound cheaper than the same strength of straight dynamite, and the 40 per cent strength of either kind is likewise 1 to 2 cents per pound cheaper than the 50 per cent strength.

The size of the charges, the depth, and the distance apart depend on the conditions present in each case. For each size of charge there is some definite depth at which a broad, clean-cut, U-shaped ditch will result, and which will give the maximum amount of excavation per pound of explosive. When a charge is placed too deep for its strength, loose dirt will be left on the sides of the ditch, and when not deep enough the full power of the dynamite is not used.

---

[2] YARNELL, D. L. EXCAVATING MACHINERY USED IN LAND DRAINAGE. U. S. Dept. Agr. Bul. 300, 59 p., illus., 1922. (Rev.)

The proper size and spacing of charges to give a clean-cut ditch of the desired depth must be determined experimentally for each set of conditions. This can best be done by firing a number of single charges, and when a size of charge is found which gives a smooth crater of the desired depth, a little less than the half diameter of the bottom of the crater will be the proper distance between charges, for the electric method. The proper distance between charges for the propagated method can be found only by trial. For a ditch 3 feet deep and 8 feet wide on top, in a saturated soil, it will be found that charges about as follows will be required: For the propagated method, 1 stick of 50 per cent straight dynamite, in holes 30 inches deep and 18 inches apart. For the electric method, 2 sticks of 40 per cent extra dynamite, in holes 30 inches deep and 30 inches apart.

The cost of ditch excavation by dynamite varies greatly. Under favorable conditions a pound of dynamite will blow out from 1 to 2 cubic yards of earth, making the cost for the explosive from 15 to 30 cents per cubic yard. Very little labor is required for such ditching. A gang of four men will load and shoot about 600 linear feet of single-row charges per day. It is usually necessary to remove débris and smooth the sides and bottom of the ditch with shovels after blasting. This work should be done as soon as possible, and if done promptly should not cost more than 1 cent per linear foot of ditch. This method is very useful for straightening streams.

Detailed directions for the handling, loading, and firing of charges for ditches can be obtained by addressing any of the manufacturers of explosives.

UNDERDRAINAGE

Underdrainage is the removal of excess water from the soil where the roots of the crops are to grow and find food for the plants. It is usually accomplished by pipes or covered channels, into which the water flows by gravity and through which it is carried and discharged into some lower natural or artificial drain.

Poles, brush, stones, and lumber have been used for underdrains, and when properly installed have provided fair drainage for a time. Usually, however, the length of time that such drains work well is short, for they become obstructed by the decaying wood or by an accumulation of silt.

In some localities, where the soil is a clay or clay loam, mole drains have proven satisfactory for short periods. Such drains are constructed by a mole plow (fig. 4), consisting of a short cylinder of iron about 4 inches in diameter with a sharp point, connected to a beam by a sharp shank about 4 feet long, made so that the distance of the cylinder or shoe from the beam can be varied from 2 to 4 feet. The plow is pulled along the course of the desired drain with the shoe at a depth of from 2 to 2½ feet. The cut made by the shank closes after the plow, while that made by the shoe remains open and acts as a drain. In rocky soils, or where stumps and other obstructions occur, this type of drain is not feasible. Neither is it feasible in loam or sandy soils. In clay or clay loam, mole drains have sometimes operated effectively for a number of years, but they can only be considered as a temporary expedient, and their use is not recommended under ordinary conditions.

The tile drain is undoubtedly the best underdrain. It consists of tile laid in the soil in a continuous line and upon such a grade that any water which finds its way into it will be carried by gravity to some lower point. The water enters the tile line through the joints between the tile, and not through the walls of the tile as many suppose. The walls of most porous tile will absorb water quickly until saturated, but no appreciable amount of water passes through the walls. Porous tile are no more efficient than impervious tile, and are very likely to be soft and easily broken or crushed. The movement of the water through the soil and into the tile is due to the action of gravity and not to a sucking or pumping action in the drains.

PLANNING A TILE DRAINAGE SYSTEM

The first essential for a tile drainage system is a suitable outlet. Without this the system will be a failure, no matter how carefully

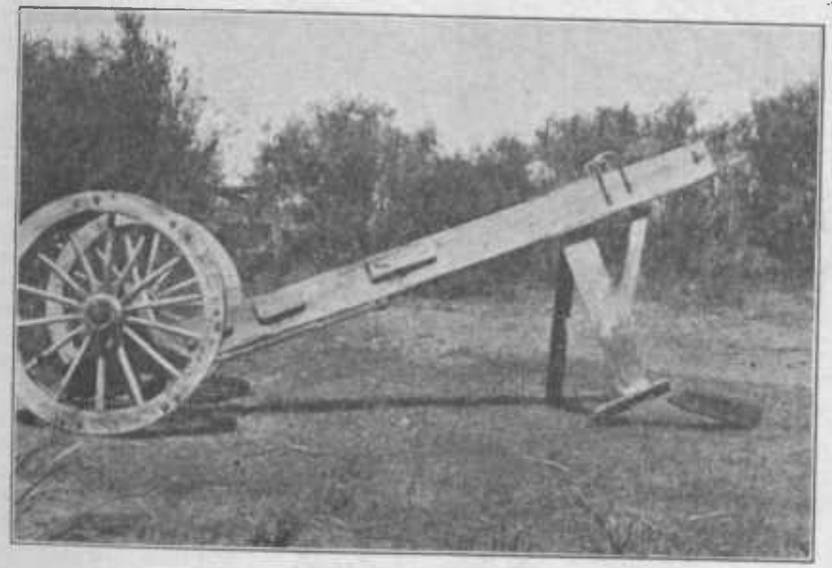

FIGURE 4.—Mole ditcher

constructed. The outlet channel may be a natural watercourse, a large open ditch, a small field ditch, or another tile drain. It is important to select an outlet that is large enough to carry the flow reaching it without submerging the tile for too long a time during periods of heavy rainfall. The ideal outlet permits a free flow from main at all times.

In the majority of cases an adequate natural watercourse or drainage ditch is available to carry away the water discharged by the tile system. Often, however, an outlet channel must be provided before a system of underdrains that will operate successfully can be constructed. On extensive flat areas with limited natural drainage, the construction of outlet ditches frequently requires the cooperation of a number of interested landowners. A majority of the States have drainage laws that provide for such cooperation. Those laws usually provide for the organization of drainage districts having

authority to construct and maintain outlet ditches or drains, and to assess each landowner within the district a share of the cost proportionate to the benefit he derives.

LOCATION OF DRAINS

The location of tile drains is controlled largely by the location of the outlet and the topography of the area to be drained. Where the land is more or less rolling, a farm may sometimes be thoroughly drained by laying random lines of tile where the soil is too wet for profitable cultivation. In such cases the drains should be located in the course of the natural flow, or so as to serve the portions of the field that are in particular need of drainage. Such a method of drainage, illustrated in Figure 5, is known as a random system.

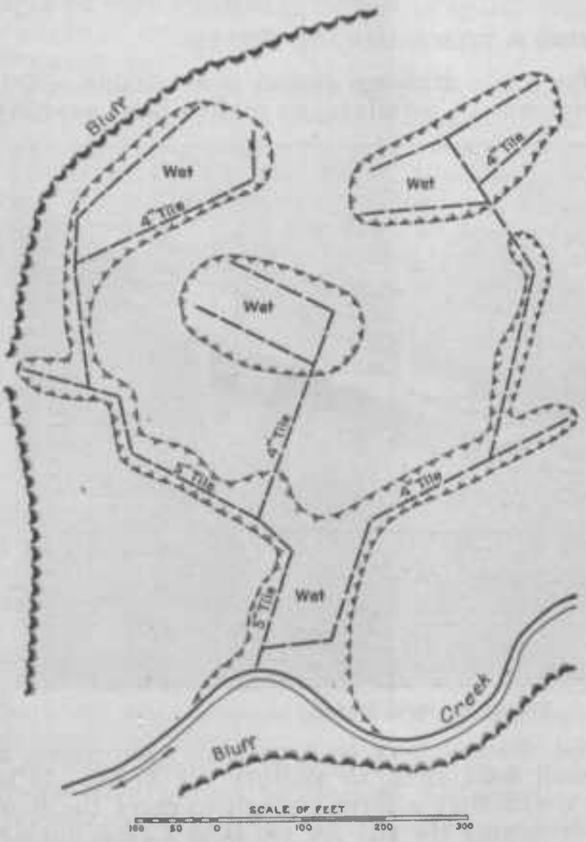

FIGURE 5.—Typical plan of random drainage

On land that is uniformly too wet for cultivation it is advisable to construct a complete system of underdrainage; that is, a system of main-outlet drains with parallel lateral drains under the whole area. Such a system is shown in Figure 6. In general, the main drains should follow the courses taken by the surface water in passing off the land during periods of heavy precipitation. The laterals should be straight and run in the general direction of the greatest slope; they should be arranged in groups of parallel lines laid at such intervals and at such depths as the soil requires. A system of short mains with long laterals is most economical, as the mains drain the land for a certain distance on each side and the laterals through this drained belt serve only to conduct the water to the mains. One main should serve as many laterals as possible to keep the number of tile outlets at a minimum, for outlets always require more or less attention if the drains are to operate efficiently.

Where entire fields would be benefited by underdrainage and the landowner does not have sufficient money available to construct a

complete system, it is frequently possible to drain parts that need it most with a random system and leave the balance of the work until a later date. The results obtained from the drains first installed can be carefully studied and the location of additional drains needed can be determined. In constructing a random system in this manner it is necessary to keep in mind the requirements of the complete system, that the random lines shall be large enough and deep enough to take the discharge from the future laterals. By proceeding in this manner the maximum profits will be received from the money expended, and the increased returns from the drained land can be expended in completing the improvement. Figure 6 illustrates a comparatively level field to be drained first by random lines of tile designed to be

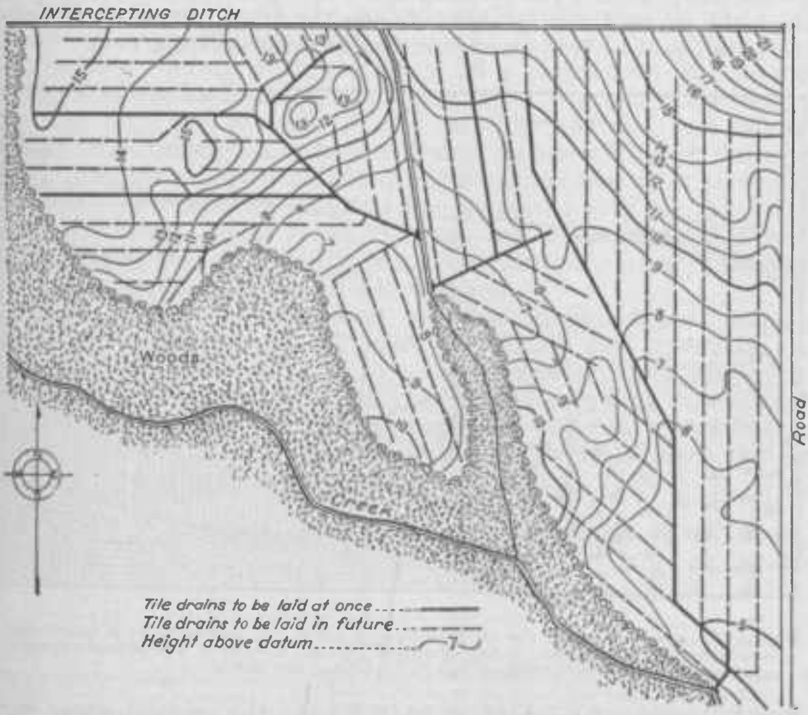

FIGURE 6.—Random drainage system with provision for complete drainage to be installed later

used as the mains in a complete drainage system to be constructed later.

When the area to be drained is of considerable size and nearly level, it is always advisable to employ a competent drainage engineer to make a survey of the area and locate and stake out the drains. Where the land has plenty of fall and the areas to be drained are small it is frequently possible for the landowner to locate the drains during wet periods, and to construct them at such times as the general farm work permits.

DRAINING SEEPY HILLSIDES

Wet areas along hillsides usually are caused by an impervious layer of soil that stops the downward flow of the water, so that it is

discharged on the surface at a point near where the subsoil comes to the surface, and the soil is thus kept too wet for cultivation. This condition can be corrected by laying a tile drain above the line where the ground becomes wet, and deep enough to intercept the water flowing along the top of the impervious layer, as shown in Figure 7. The drain should run across the slopes as nearly parallel to the seepy place as possible.

DEPTH AND SPACING OF DRAINS

The proper depth of drains and their distance apart are determined largely by the texture of the soil. The ground-water level is lowered between drains in a curved line, the highest point being midway between the drains. The spacing and the depth should be such as to reduce the ground-water table between the tile lines to an elevation most beneficial to plant growth within 24 hours after a rain.

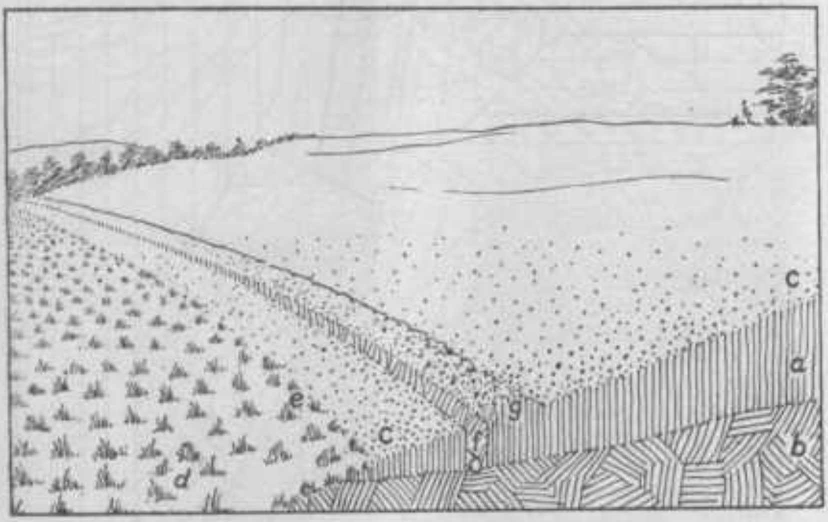

FIGURE 7.—Proper location for an intercepting drain. *a*, porous soil; *b*, impervious strata; *c*, cultivated land; *d*, wet or seeped ground; *e*, edge of wet ground; *f*, intercepting drain; *g*, waste bank of trench excavated for drain

The rapidity with which a drain lowers the ground-water curve depends upon the ease with which water percolates through the soil. The amount of coarse sand in the soil is one of the elements affecting the rate of percolation of water. In sandy lands the drains may be placed deeper than in clay lands, and accordingly may be spaced farther apart. The presence of "joint clay" formation in the subsoil is a great help to under-drainage as the water will follow the joints. In tight clay soils the movement of soil water is very sluggish, and underdrains must be placed at less depth and closer together than is the case in soils with a more open texture.

In general it can be stated that in clay soils it may be necessary to place drains from 40 to 70 feet apart and from 27 inches to 3 feet deep. No tile should be laid less than 27 inches deep, that is, the bottom of the trench on which the tile is laid should be at least 27 inches below the ground surface. In the more open soils, such as

sandy loam, it may be sufficient to space drains 80 to 200 feet apart and from 3 to 4 feet deep. A spacing closer than 50 feet makes drainage so expensive that it usually is not recommended unless the land is to be used for trucking or some other type of crop from which the returns are large.

SIZE OF TILE

The size of tile for the main and submains of a tile system are determined largely by the area drained, the surface conditions, the porosity of the soil, and the grade or fall available for the drain. The required capacity of a drain is nearly proportional to the acreage from which the water comes, other conditions being the same. An area from which all the water must be removed by the underdrains will require larger tile than one which has good surface drainage, because surface channels carry off a large part of the water during a storm and underdrains then have to provide for only the part that seeps into the soil. Water passes through an open soil more rapidly than through a close soil; hence, water will reach the drains faster through a porous soil than through one that is relatively impervious. The capacity of a tile line increases with the rate of fall along the drain, being about twice as much at a fall of 4 inches in 100 feet as at 1 inch in 100 feet. Therefore the greater the grade or fall the smaller the size of tile required.

Four-inch tile is the smallest size that should be used for land drainage. Smaller sizes are more difficult to lay accurately, and are much more easily clogged by a small amount of silt getting into the line. A 4-inch tile has fully twice the carrying capacity of a 3-inch tile, and the difference in cost is not sufficient to warrant the risk involved in using the smaller drain. Table 1 shows the comparative capacities of different sizes of tile lines.

TABLE 1.—*Comparative capacities of tile*

One	Will carry the discharge of
5-inch	Two 4-inch.
6-inch	Three 4-inch, or one 5-inch and one 4-inch.
8-inch	Six 4-inch, or two 6-inch or three 5-inch.
10-inch	Eleven 4-inch; or one 8-inch, one 6-inch, and one 5-inch.
12-inch	Eighteen 4-inch; or one 10-inch, one 8-inch, and one 4-inch.

Experience indicates that where no surface water is admitted to the underdrains, tile systems in ordinary loamy soils generally should be designed with sufficient capacity to remove one-fourth inch depth of water over the area drained in 24 hours. In some of the more pervious soils that permit the water to pass through rapidly, such as very sandy loose loams, it is advisable for the drains to have a capacity of three-eighths inch depth of run-off per 24 hours. When surface water is admitted to the underdrains, as through surface inlets, the size of the tile should be increased so as to carry a run-off of three-fourths inch to 1 inch per 24 hours.

Table 2 gives the area in acres from which one-fourth inch of water will be removed in 24 hours by various sizes of tile laid at grades ranging from five-eighths inch per 100 feet to 12 inches per

100 feet. When three-eighths inch run-off is to be provided, two-thirds of the areas given in the table should be used. Where surface inlets will admit large quantities of surface water, the tile will give drainage to but one-fourth of the areas stated in the table.

TABLE 2.—*Areas from which one-fourth-inch run-off per 24 hours can be drained by tile mains*

[Table compiled from diagram of discharge curves for tile based on the Yarnell formula $V=138\ R^{2/3}\ S^{1/2}$]

Size of tile (inches)	Fall per 100 feet			
	⅝ inch or 0.05 foot	1¼ inches or 0.1 foot	2⅜ inches or 0.2 foot	3⅝ inches or 0.3 foot
	Acres drained			
4		6	9	12
5	8	12	17	21
6	13	20	28	35
8	31	43	62	75
10	55	79	110	138
12	90	128	180	220
Size of tile (inches)	4¾ inches or 0.4 foot	6 inches or 0.5 foot	9 inches or 0.75 foot	12 inches or 1.0 foot
	Acres drained			
4	14	15	19	22
5	25	28	34	40
6	41	45	56	64
8	87	98	120	138
10	158	177	215	250
12	255	280	345	410

Experience indicates that when small size tile drains are laid at minimum grades their length should be limited to those given in Table 3.

TABLE 3—*Limit of length of tile lines at minimum grade*

Size of tile	Minimum grade	Limit of length
Inches	*Feet*	*Feet*
4	0.10	2,500
5	.07	3,000
6	.05	3,600

SELECTING TILE

Draintile should be circular in cross section and approximately straight. The inside should be smooth, and the ends should be regular and smooth enough to admit of making close joints. Tile smaller than 10 inches in diameter should have a length of 12 inches; large tile may be 18, 24, or 30 inches in length according to the size.

Good tile should be free from visible grains or masses of lime or other minerals that cause slacking or disintegration; a broken surface should show a uniform structure throughout. The tile should

be free from chips or cracks that would decrease the strength materially, and when dry they should give a clear ring if stood on end and tapped with a light hammer.

In constructing tile drains it is very important to use tile that have sufficient strength to withstand the pressure to which they are subjected, and that can withstand the action of the chemicals in the soil water that flows through them. The American Society for Testing Materials has prepared specifications for draintile, and it is good practice in making purchases to stipulate that the tile furnished shall meet the requirements of those specifications. For sizes smaller than 12-inch, the quality termed "farm" drain tile are sufficient for the usual conditions of draining farm lands; larger sizes should be of the "standard" quality. The specifications cover both clay and concrete tile.

CLAY TILE

Clay draintile are classified as either common or vitrified tile. The former are made from common brick clay which, when well burned, makes a good quality of building brick. The vitrified tile are made of ground shale or of a high grade clay, frequently mixed with common clay, and in some instances are salt glazed. They are stronger and less porous than the common clay tile and are usually more resistant to frost action. Either kind, when well made, is satisfactory for farm drainage.

CONCRETE TILE

Concrete tile have been extensively used in the Middle West. When properly made they have proven satisfactory in soils where acids and alkali salts are not present. Such tile must be made of clean sand and gravel, properly mixed and cured. To make good concrete tile proper equipment and careful supervision by men experienced in such work are required. The making of tile on the farm by using molds or small hand machines is usually not advisable as proper facilities for making and curing are not available. Concrete tile should be purchased from a factory that is well equipped and is known to be making a good quality of tile. Where the soil or ground water contains acids or alkali salts, special investigation should be made to determine the quality of tile required to resist the effects of those chemicals.

CONSTRUCTING THE TILE DRAIN

HAND TOOLS

The tools most commonly used in trenching and laying tile by hand are tile spades, shovels, drain scoops, and the tile hook. (Fig. 8.)

The tile spades are of two kinds—solid and open—and are from 16 to 22 inches long; the 18-inch and 20-inch sizes are most used. The open spade is used in digging mucky or sticky soils. The shovel used is of the ordinary long-handled, round-nosed type. The drain scoop is semicylindrical in shape and is fitted with a long handle; it is made in sizes to fit tile from 4 to 8 inches in diameter. The tile hook is made of ½-inch round iron—the long part being 9 inches and the short part 4 inches in length—fastened to an ordinary rake handle.

ESTABLISHING GRADE

When using inexperienced labor, probably the best method of establishing grade is that of gage and line. This method consists of stretching a cord at a uniform height above the bottom of the trench to be dug, and measuring down from the cord with a gage stick, as illustrated in Figure 9. The cord should be placed high enough above the bottom of the trench so that it will not interfere with the workmen.

The trench is marked out by stakes set 50 feet apart. At each 50-foot station there are two stakes, one with its top about level with the surface of the ground and known as a "grade hub," the other standing a foot or more above the ground and called a "guard stake." All measurements are made from the top of the grade hub. The guard stake locates and gives the number of the hub; upon it may be marked the required depth of the trench below the top of the

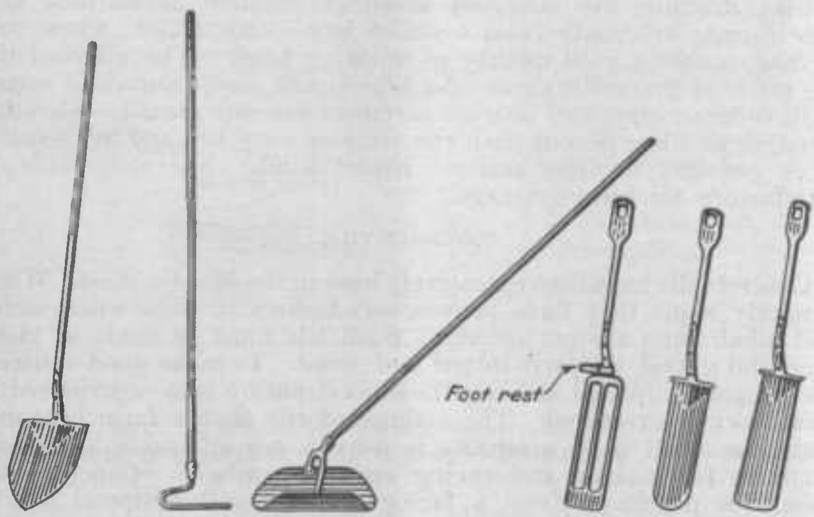

FIGURE 8.—Tile-drainage tools

hub. The gage for measuring to the bottom of the trench is usually a stick 1 by 2 inches. For ordinary farm tile work, an even 6 feet is a good length.

To dig the trench to the proper grade, proceed as follows: Drive a strong stake upright near the hub and another on the opposite side of the trench, as shown in Figure 9. Across the trench place a bar with its top edge above the hub at a height equal to the difference between the length of the gage and the depth of cut at that station. The crossbar should be set level by the use of a carpenter's level. A convenient way of fastening the crossbar to the uprights is by means of clamps as illustrated. Set similar crossbars at three or more stations, and over the center line of the trench stretch a light, strong cord (preferably fishline), taut across the tops of the bars from one station to another. If the fall is uniform, any error in establishing grade can be detected by sighting over the crossbars. The trench

bottom is at correct grade when the gage is stood upright in the trench and its top just touches the grade cord. The bottom of the gage must be kept clean, as any adhering dirt will result in incorrect grade.

In Figure 9 a cut of 3 feet, 11 inches is indicated at the hub in the foreground. Subtracting this cut from the length of gage (6 feet), the difference of 2 feet, 1 inch is the height for setting the top of the crossbar above the top of the hub. The gage in the foreground indicates that the trench has been dug to proper grade at that point.

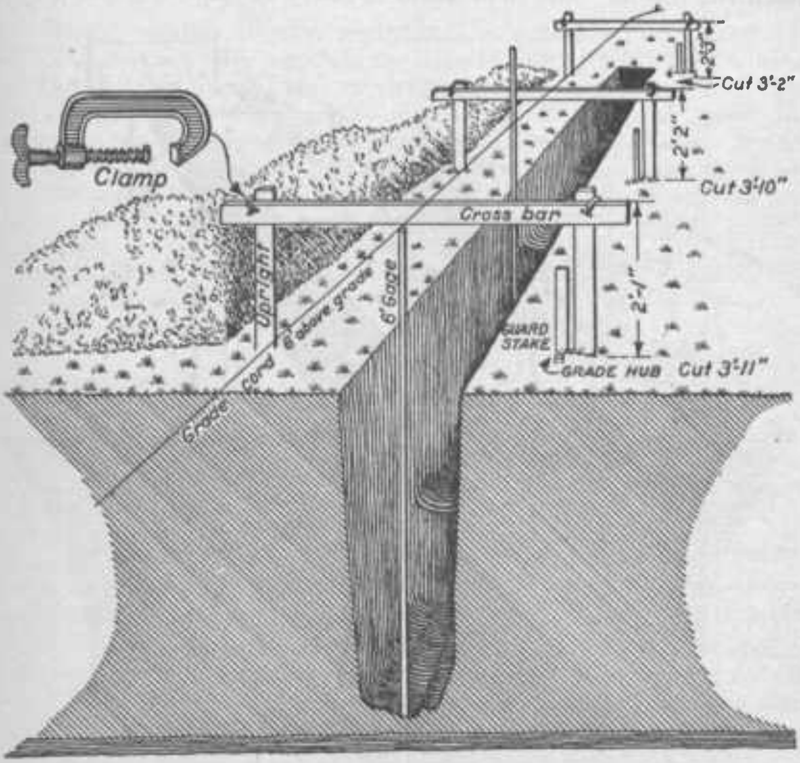

FIGURE 9.—Crossbar method of establishing grade for a tile drain

The other gage indicates that further digging is required, the amount being shown by the length that the gage extends above the cord.

A slightly different method of obtaining proper grade, widely used by experienced tile layers, is shown in Figure 10. A gage about 5 feet long is used, and instead of crossbars, white chalk lines are stretched across the trench, held in place by wooden stakes or iron rods. The height of these lines above the hubs is, as before, the difference between the depth of cut and the length of the gage used. Three or more of these chalk-line "targets" should be used at a time. The grade is determined by sighting over the top of the gage and the lines. If these line up, the trench is at grade; if the top of the gage projects above the line of sight established by the targets,

the trench is not deep enough; if the top of the gage drops below the line of sight, the trench is too deep. Usually it is more convenient to sight down rather than up the completed trench. However, when starting from the outlet, as in Figure 10, or when passing a point where the grade changes, it is necessary to sight upstream until the next station is passed.

IMPORTANCE OF CORRECT LEVELS

Attention is called to the importance of having no sags in a completed tile drain. Any depression is likely to cause a settling of silt

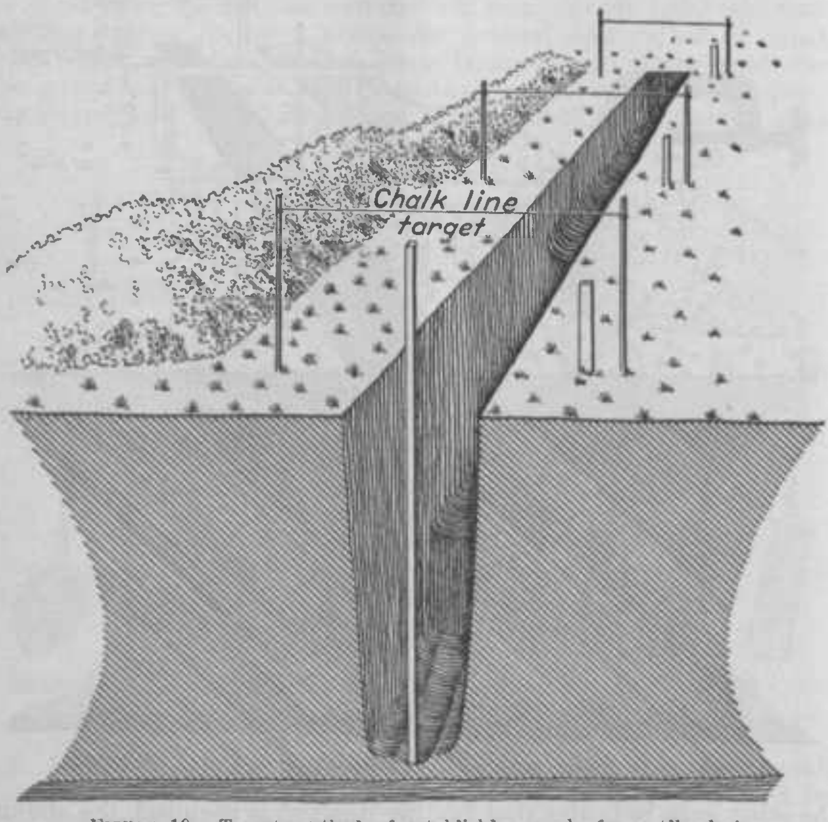

FIGURE 10.—Target method of establishing grade for a tile drain

in the tile, which will result in partial or even total obstruction of the drain. Where the available fall is slight, the determination of the levels upon which the construction work is based must be done accurately. For this reason it is advisable that these preliminary levels be determined with an engineer's level where practicable, and that one of the foregoing methods of establishing grade be used. The less the available fall, the greater the necessity for accurate work.

When the fall is 3 inches or more per 100 feet, fairly good results can be had by establishing the tile grades with an **A** frame used in connection with a carpenter's level. Such a device is shown in Figure 11. The legs ab and bc may be of 1 by 4 inch lumber, 12

feet long. The distance ae is 16 feet 6 inches (1 rod). The brace upon which the level rests should be absolutely straight and so set that when the legs of the frame rest on a perfectly level surface the level bubble is at the center of the tube. Any desired fall can be obtained with this device by nailing a block upon the bottom of one leg; a 1-inch block as shown in Figure 11 will give a fall of 1 inch per rod. Care must be taken to see that no dirt adheres to the bottoms of the legs, as this will seriously affect the grade.

DIGGING THE TRENCH

Trenching should always begin at the outlet and proceed upstream. For small tile, trenches are usually dug 10 to 15 inches wide, according to the depth, and with practically vertical sides. The trench is dug with a tile spade to within 1 or 2 inches of grade, and then the bottom is cleaned out to grade with the drain scoop. Standing in the trench ahead of the tile that have been laid, the workman draws the scoop toward him, leaving the trench bottom smooth and rounded to fit the lower part of the tile. Care should be taken not to excavate below grade.

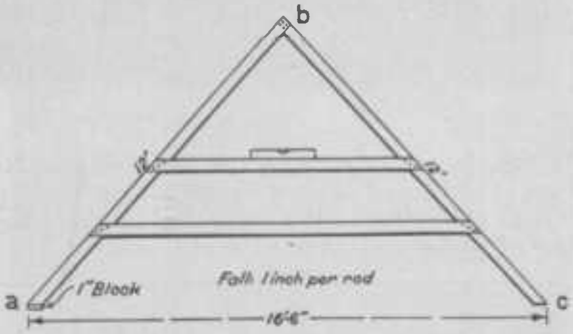

FIGURE 11.—Homemade A-frame level for use in constructing drains

TILE-TRENCHING MACHINES

Where the amount of work to be done is large and labor is scarce it is frequently advisable for the landowner to purchase some form of tile-trenching machine or to have the drains constructed by a contractor who has such a machine. The cost of trenching by machinery is not greatly different from that by hand labor. The main advantages of machine work over hand labor are that fewer men are required and that the work is completed more rapidly.

Tile-trenching machinery may be divided into two general classes—horse-drawn trenching plows and power-operated trenching machines. The ditching plows are comparatively inexpensive implements (costing from $20 to $500), which will excavate trenches suitable for smaller sizes of tile. (Fig. 12.) They can frequently be used to advantage in digging the top 18 inches or 2 feet of the trench. However, hand labor is necessary to dig the trenches to grade after such plows have been used. Power-operated trenching machines are of two general types, wheel excavators and endless-chain excavators; those generally used in farm drainage cost from $3,500 to $4,500. Figure 13 shows a wheel excavator in operation. A detailed description of power-trenching machines can be found in another bulletin.[3]

[3] YARNELL, D. L. TILE-TRENCHING MACHINERY. U. S. Dept. Agr. Farmers' Bul. 1131, 22 p., illus., 1923. (Rev.)

LAYING THE TILE

Tile laying, like trenching, should begin at the lower end or outlet and progress upstream, following closely the excavation of the trench. In placing the tile, they should be turned until the ends

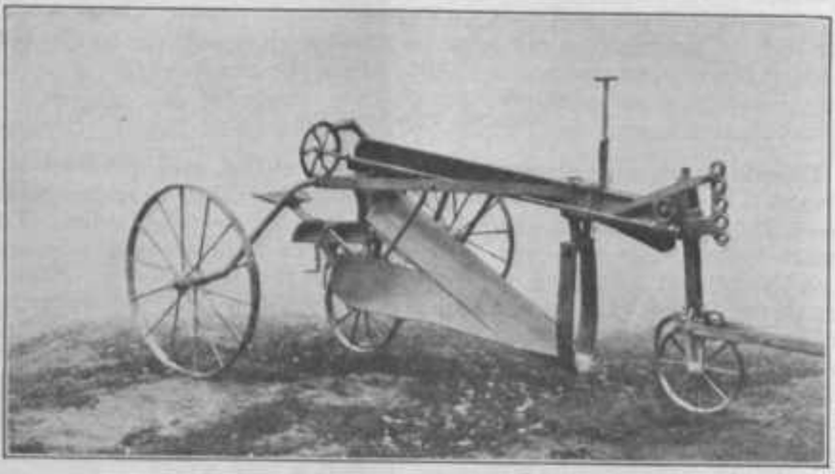

FIGURE 12.—Trenching plow

fit together tightly. If a tile is crooked or the ends are irregular it should be turned until it fits tightly at the top, the open space being left at the bottom. Where, owing to irregular ends, a crack or opening of one-fourth inch or more must be left at the top or sides, it

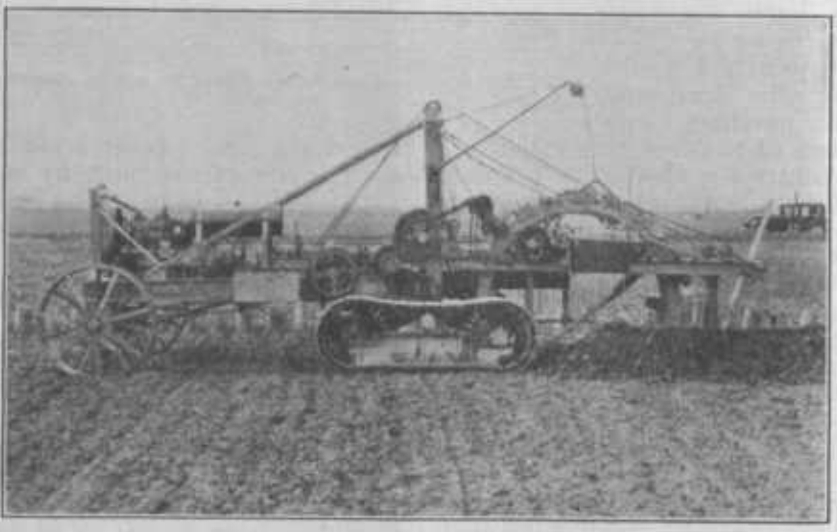

FIGURE 13.—Wheel-type trenching machine

should be covered with pieces of broken tile, strips of tar paper or, in some sandy soils, with cement mortar.

Tile up to 6 inches in diameter can be placed either with a tile hook by a man on the trench bank or by hand by the man who is

finishing the trench with the tile scoop. It has been found that with unskilled labor the best results are obtained if the man using the tile scoop works backward up the trench, laying the tile as fast as he finishes the grade.

If the trench has been dug below grade in dry materials, the bottom can be built up to grade with moist earth, well tamped. In a wet, soft trench it may be advisable to lay the tile on plank bedded at grade. Where saturated fine sand or sandy loam is encountered, it is necessary to prevent the soil from washing into the tile through the joints, by wrapping the joints with cloth or tar paper. In laying tile through quicksand it is well to have the assistance of a man experienced in such work.

FIGURE 14.—Tile junction

All tile that are cracked, soft, or poorly-shaped should be laid aside; these tile are not wasted, unless there is an excessive number of them, as it is necessary to have broken tile to patch junctions and poor joints. It is very important that the tile be laid and "blinded" (see page 20), as soon as the trench is completed to grade. This is necessary as otherwise caving of the banks and softening of the bottom may occur. The end of the tile line should be closed whenever the workmen leave the job, to prevent dirt getting into it; and when completed each line should be closed at its upper end by a brick or piece of broken tile.

MAKING JUNCTIONS AND CURVES

Junctions should be made by Y's (fig. 14) not by T's nor by elbows. Practically all tile factories now make junction tile, and these should be obtained if possible. If Y's can not be obtained, junctions can be made by cutting and fitting together straight tile. When this is done care must be taken to prevent the branch tile

from projecting into the main. Unless the lack of fall prevents, there should be a drop from the branch into the main, which can be obtained by turning the Y slightly in its bed so as to elevate the branch.

Changes of direction should be made by curves and not by sharp angles. These curves should be regular, with the outside of the joints covered by pieces of broken tile (fig. 15), or, for a sandy soil, the ends of the tiles can be chipped off on the insides of curves with a hammer or by catching the tile between the jaws of a monkey wrench and bearing down on the handle.

BLINDING THE TILE

The tile should be covered the day they are laid, with loose earth to a depth of 4 to 6 inches, so that they may be held in place. This should be done carefully in order not to displace the tile.

BACK FILLING THE TRENCHES

Trenches should be filled soon after the tile are laid. For this purpose a plow can be used with two horses, one on either side of the trench, attached to a long evener. One side is plowed while going in

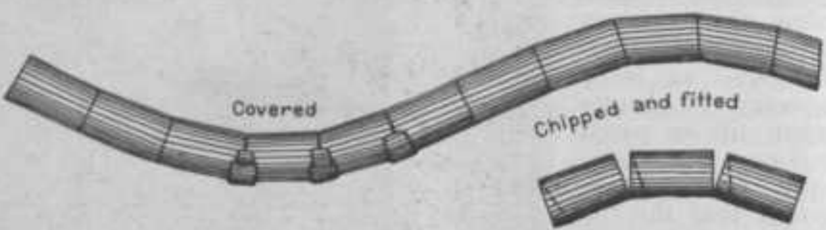

FIGURE 15.—Curves in tile line

one direction, and the other side on the return trip; usually two rounds of the plow are sufficient to back fill a ditch. A scraper made from a 2 by 12 inch plank, 4 feet long, can be used to good advantage in many cases. The horses in this case work at right angles to the trench, scraping in the earth piled on the bank. If this method of back filling is to be used, it is advisable to throw all the earth dug from the trench on one side rather than on both sides. Road-grading machines can also be used for back filling trenches.

PROTECTING THE OUTLET

The outlet end of a tile drain should be protected by a head wall of brick, stone, or concrete. If not more than 4 feet high, the head wall should be 16 inches thick and should extend from the ground surface to at least 1 foot below the bottom of the ditch in front of the head wall. For higher walls the thickness should be increased proportionately. A typical head wall is shown in Figure 16. Tile outlets are often damaged by washing out and caving unless protected in a substantial manner. The joints of the first 10 feet next to the head wall should be cemented. Where freezing occurs, the first 10 feet of drain should be of vitrified pipe or second-grade sewer

pipe. A cushion of concrete or stone should be built in front of the outlet to prevent the water from undermining the head wall.

Burrowing animals such as muskrats and rabbits often obstruct tile drains by entering at the outlet and building nests in them. Where this trouble is likely to occur, it will be well to hang a screen over the end of the drain as shown in Figure 16. A screen permanently fixed over the outlet catches trash washed down the drain, especially in systems where surface inlets are used. Ordinarily, surface water which follows the depression over the tile line should be diverted so as not to discharge over or around the head wall.

SURFACE INLETS AND SILT WELLS

The purpose of the surface inlet is to admit surface water directly into the drain. The office of the silt well is to catch and retain any silt suspended in the water. These two devices are often combined in one structure. The surface water enters through the top, while the drain water enters through the tile at one side and flows out at the other. Two or more lengths of sewer pipe set on a concrete base make a satisfactory surface inlet, or a concrete-box inlet may be built. (Fig. 17.) At the top should be placed an iron grating,

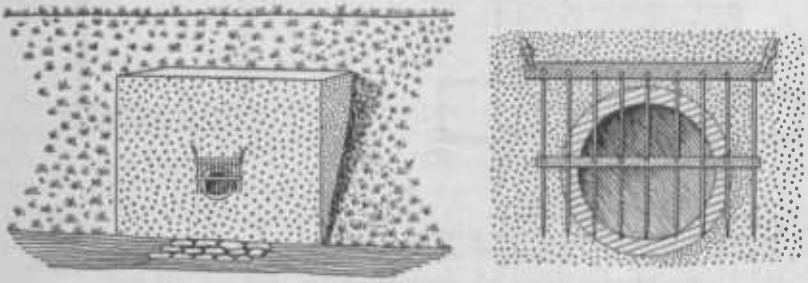

FIGURE 16.—Typical head wall for tile outlet

which may be covered with broken brick or small stones to act as a coarse filter. From time to time the brick or stone should be rearranged and the silt removed from the bottom of the catch basin. If only a small amount of surface water is to be handled, a satisfactory inlet can be made by filling a section of the trench with broken brick or tile, or with gravel, as shown in Figure 18. Under certain conditions the use of surface inlets will greatly increase the effectiveness of the drains, especially in heavy clay soils where percolation through the ground to the tile is naturally slow. They are seldom necessary in soils that drain readily, or that have a fair slope.

OBSTRUCTION OF DRAINS BY TREE ROOTS

Roots of trees growing in the vicinity of tile drains may penetrate the drains and obstruct the flow, especially if the tile is fed by springs or carries water far into the dry season. Under such conditions roots enter the joints of the tile in search of moisture, and masses of roots grow until they sometimes completely fill the tile. This occurs with other varieties as well as with those classed as water-loving trees. If the water ceases to flow in the tile as the surrounding land dries out, the drain in all probability will not be

obstructed by tree roots. Where there is reason to suspect that this difficulty will be encountered, the joints of the tile should be tightly cemented. As a general practice, all willows and other water-

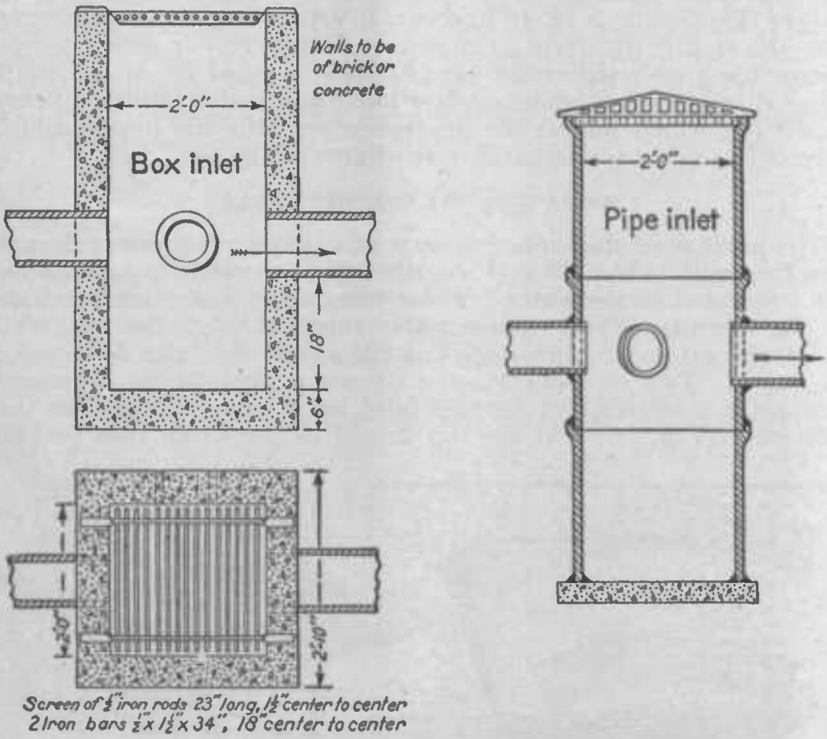

FIGURE 17.—Design for combined surface inlet and silt well

loving trees growing within 50 feet of a tile drain should be destroyed.

DRAINAGE RECORDS

A permanent record should be kept of the locations and depths of all drains. To this end all maps, plans, and profiles of the system built and notes relating to it should be preserved. Wherever

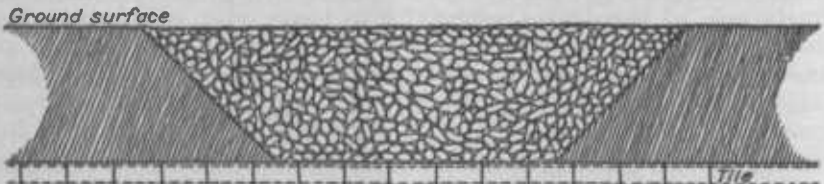

FIGURE 18.—Blind inlet

a tile line crosses or ends at a fence, farm road, or other permanent line, iron stakes or pieces of pipe should be driven in order that the drain may be easily located. The importance of this will be seen when it is desired to extend or repair drains, or to add branches.

COST OF TILE DRAINAGE

The cost of tile drainage varies greatly, depending upon the prices paid for the tile; the transportation expenses from factory to farm, including hauling and distributing the tile along the line of the drain; the cost of labor to dig the trenches, lay the tile, and back fill the trenches; and the length of drain needed.

The prices of tile vary with the section in which it is manufactured, being lowest in the Middle West where tile drainage is extensively practiced and where competition between tile factories is strongest. Most factories sell tile by the thousand feet. In the Middle West the prices prevailing in 1929 for tile at the factory, loaded for shipment, are about as shown in Table 4.

TABLE 4.—*Weights and prices of draintile in the Middle West, 1929*

Size of tile	Weight per foot	Price per 1,000 feet in carload lots
Inches	*Pounds*	*Dollars*
4	7	20–22
5	9	28–30
6	12	37–40
8	20	55–65
10	27	105–120
12	37	145–160

The expense of transportation depends upon the distance tile are shipped, and the cost of hauling them to the farm and distributing them along the line of the drain. Often the farmer can do a considerable part of the hauling.

Digging the ditch and laying and blinding the tile are generally considered as one operation, which is usually done by contract at an agreed price per rod. This price is affected by the character of the soil, the depth of the ditch, and the size of the tile. An average price for 4-inch, 5-inch, or 6-inch tile laid 3 feet deep or less is 50 to 60 cents per rod. Eight-inch tile laid 3 feet generally costs from 75 cents to $1 per rod, and 10-inch and 12-inch tile laid 3 feet deep from $1 to $1.25 per rod. For deeper drains, the prices usually increase rather rapidly with the depth.

The cost of tile drainage per acre depends upon the amount of tile required per acre, as well as upon the price factors just mentioned. Where the land does not require a uniform system of drainage the cost may not exceed $10 or $15 per acre. Where uniform drainage is required the cost will depend largely upon the spacing between drains. Drains spaced 50 feet apart may cost from $60 to $70 per acre, whereas with drains 80 feet apart the cost probably would be about $45 to $50 per acre. The lengths of drain required per acre for laterals, given in Table 5, will aid in estimating the cost of a complete drainage system for any farm when the prices for tile and labor are known. The length of the mains, which will depend upon the arrangement of the drains, must be added.

TABLE 5.—*Length of tile per acre, for laterals only*

Distance between laterals	Amount of tile required per acre	Distance between laterals	Amount of tile required per acre	Distance between laterals	Amount of tile required per acre
Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
40	1,089	65	670	90	484
45	969	70	623	95	459
50	872	75	581	100	436
55	792	80	545	150	327
60	726	85	513	200	218

VERTICAL DRAINAGE

By vertical drainage is meant the disposal of drainage water through wells into a porous soil layer or open rock formation that is capable of taking large volumes of water rapidly and in turn has outlet lower than the land to be drained. The existence of such a substratum, at a depth that can be reached without prohibitive cost, is the exception rather than the rule; and usually there is no way of foretelling whether its capacity as a drainage outlet is sufficient to be permanently effective. In the limestone regions of the United States where considerable areas have natural drainage into the "sink holes" that are more or less common, such wells can frequently be used advantageously where outlets into natural or artificial watercourses are not easily accessible, but in general the possibilities of drainage in this manner are very limited.

Drainage wells must be lined, except through rock, to keep earth from falling in and clogging the outlet. The tops, also, must be protected against the entrance of trash and sediment. The cost of such wells has many times been $90 to $200 per acre, which is much more than the assessments for outlet drainage in most drainage districts. Therefore the installation of drainage wells is not recommended where a surface outlet can be obtained at a reasonable cost, except in those unusual cases where it is certain that vertical drainage is feasible.

MAINTENANCE OF FARM DRAINS

Any drain that is to operate efficiently must be kept clean. Tile drains with good outlets, if properly constructed, rarely become clogged. The condition of the soil along a drain a few days after heavy rains always indicates how the drain is working. If wet spots occur, the water is not being carried off properly. A hole or cave in above a tile line indicates that a tile has been either broken or displaced. When this occurs, immediate steps should be taken to repair the line; otherwise the entire drain above the clogged part may become filled with silt, making it necessary to relay that part of the line.

Open ditches and the outlet channels for tile drains and the lower end of the tile lines should be inspected frequently, and all weeds, grass, briars, willows, silt, trash, or refuse of any kind that obstructs the flow of water should be removed. If this is done at frequent intervals the cost is comparatively small, but if the drains are allowed to deteriorate the cost of repairing them or redigging the ditches may equal the cost of the original improvement. The maintenance of drainage improvements is an excellent example of the adage, "an ounce of prevention is worth more than a pound of cure."

ORGANIZATION OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

October 1, 1929

Secretary of Agriculture	ARTHUR M. HYDE.
Assistant Secretary	R. W. DUNLAP.
Director of Scientific Work	A. F. WOODS.
Director of Regulatory Work	WALTER G. CAMPBELL.
Director of Extension Work	C. W. WARBURTON.
Director of Personnel and Business Administration.	W. W. STOCKBERGER.
Director of Information	M. S. EISENHOWER.
Solicitor	R. W. WILLIAMS.
Weather Bureau	CHARLES F. MARVIN, *Chief.*
Bureau of Animal Industry	JOHN R. MOHLER, *Chief.*
Bureau of Dairy Industry	O. E. REED, *Chief.*
Bureau of Plant Industry	WILLIAM A. TAYLOR, *Chief.*
Forest Service	R. Y. STUART, *Chief.*
Bureau of Chemistry and Soils	H. G. KNIGHT, *Chief.*
Bureau of Entomology	C. L. MARLATT, *Chief.*
Bureau of Biological Survey	PAUL G. REDINGTON, *Chief.*
Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Bureau of Agricultural Economics	NILS A. OLSEN, *Chief.*
Bureau of Home Economics	LOUISE STANLEY, *Chief.*
Plant Quarantine and Control Administration	C. L. MARLATT, *Chief.*
Grain Futures Administration	J. W. T. DUVEL, *Chief.*
Food, Drug, and Insecticide Administration	WALTER G. CAMPBELL, *Director of Regulatory Work, in Charge.*
Office of Experiment Stations	E. W. ALLEN, *Chief.*
Office of Cooperative Extension Work	C. B. SMITH, *Chief.*
Library	CLARIBEL R. BARNETT, *Librarian.*

This bulletin is a contribution from

Bureau of Public Roads	THOMAS H. MACDONALD, *Chief.*
Division of Agricultural Engineering	S. H. MCCRORY, *Chief.*

U. S. GOVERNMENT PRINTING OFFICE: 1929

For sale by the Superintendent of Documents, Washington, D. C. - - - - - Price 5 cents